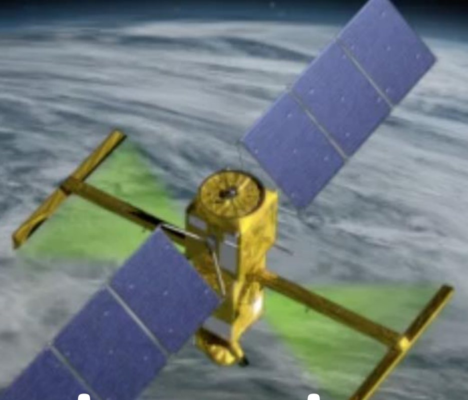

SWOT ocean in-situ CalVal

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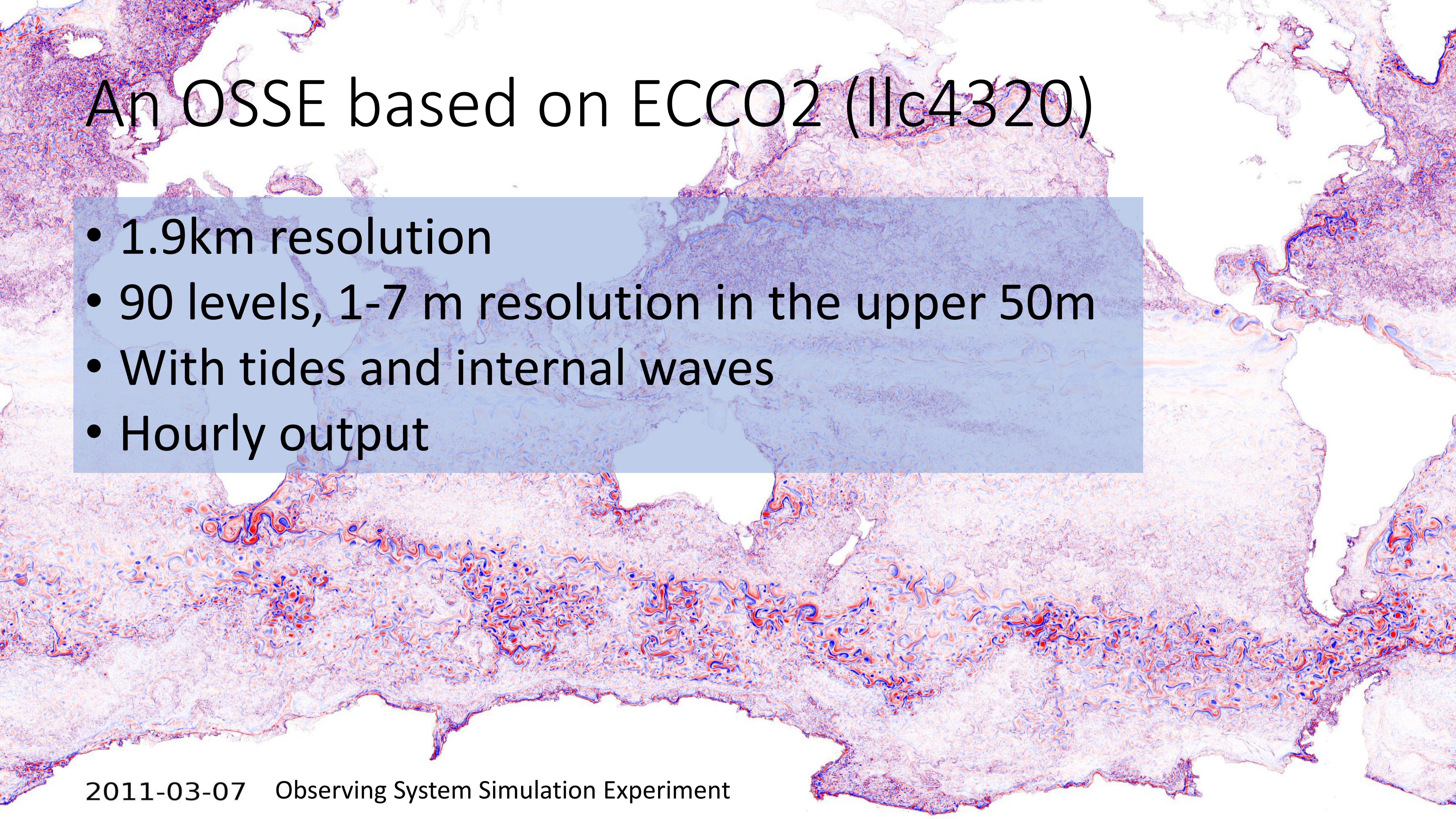
5. California Institution of Technology, Pasadena, CA, 91125

Thanks to Patrice Klein, Sarah Gille, Steve Chien, Rosemary Marrow

SWOT ST Meeting, Toulouse, 6/26/2017

An OSSE based on ECCO2 (llc4320)

- 1.9km resolution
- 90 levels, 1-7 m resolution in the upper 50m
- With tides and internal waves
- Hourly output



Mission requirement based on wavenumber spectrum

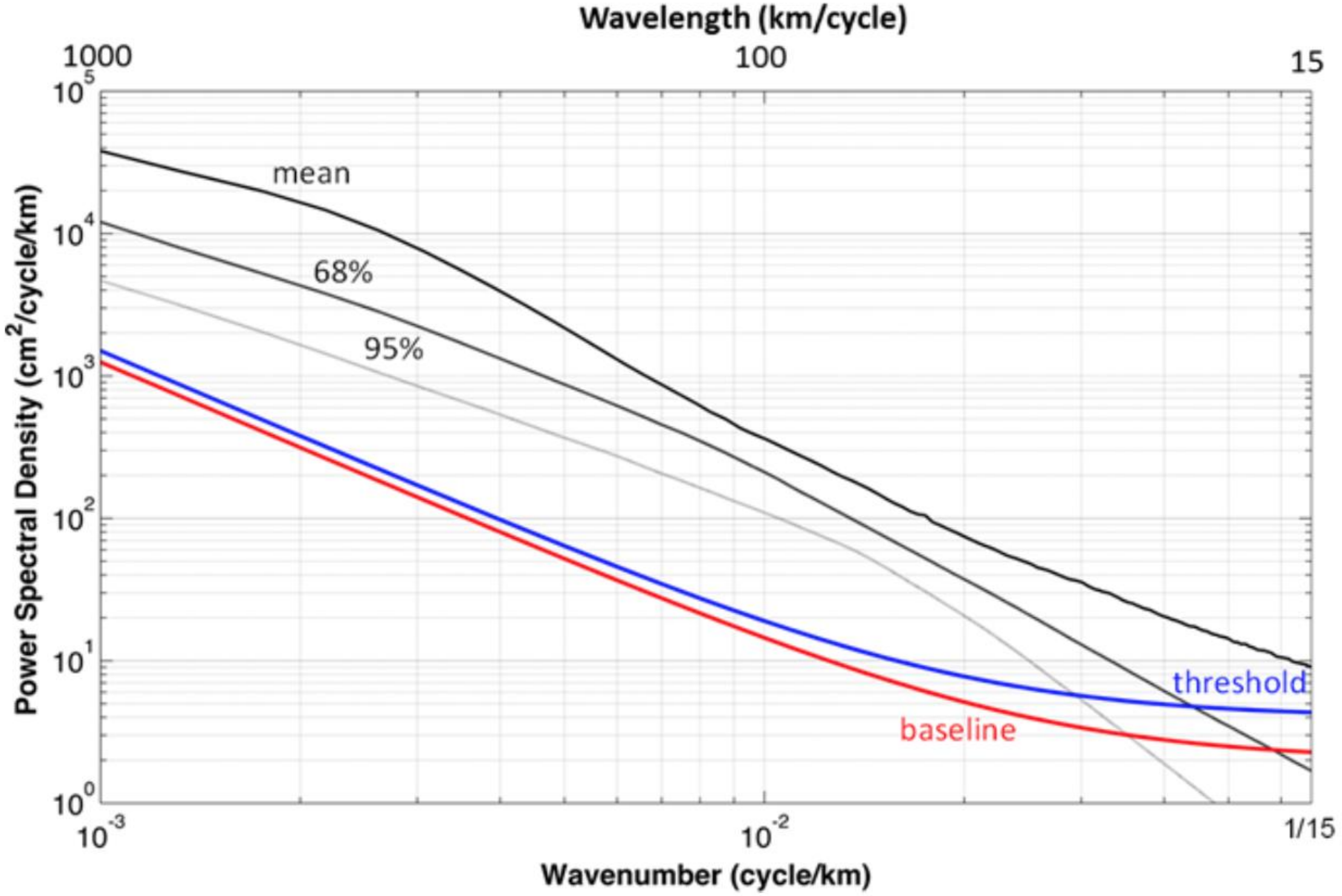
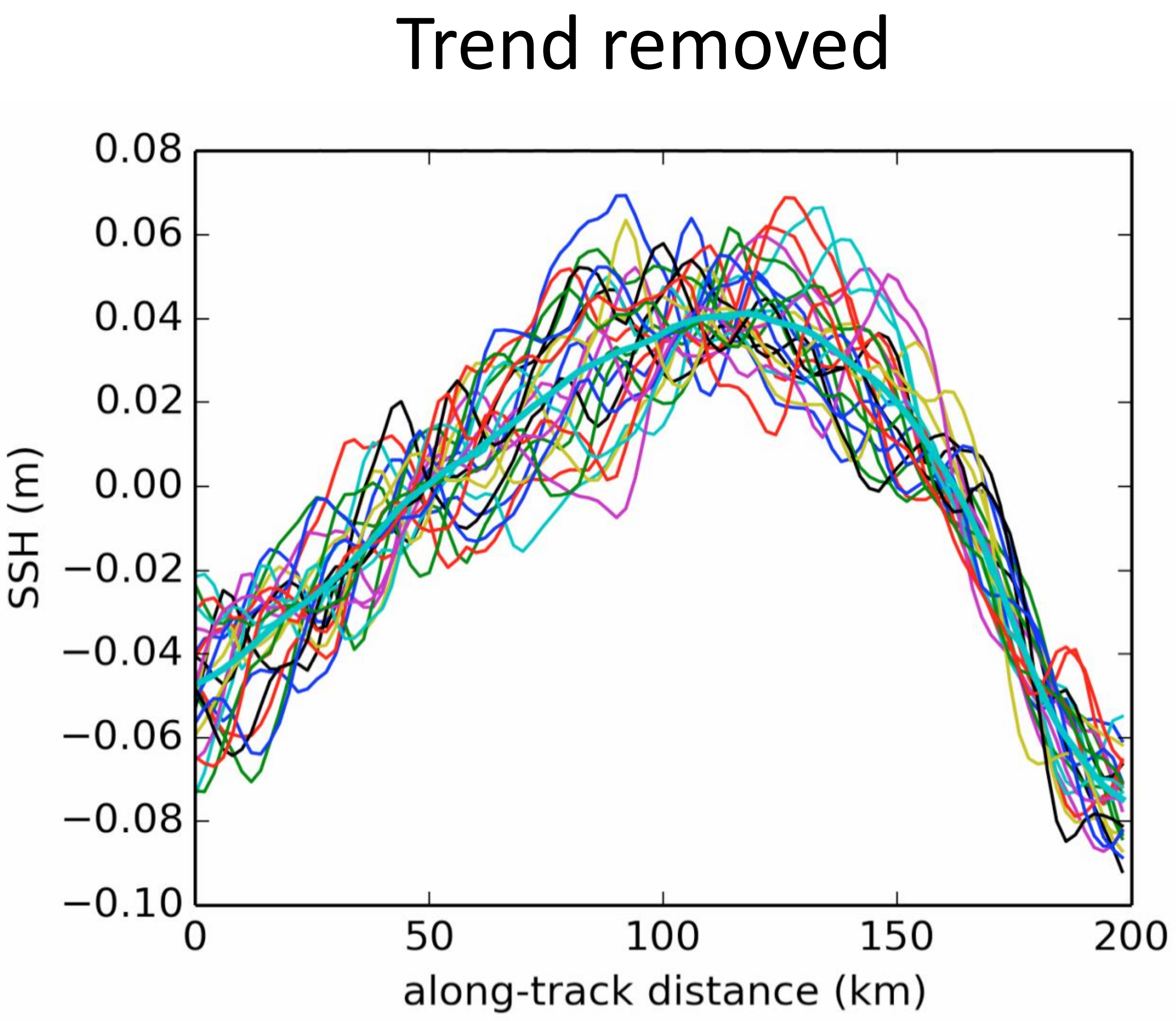
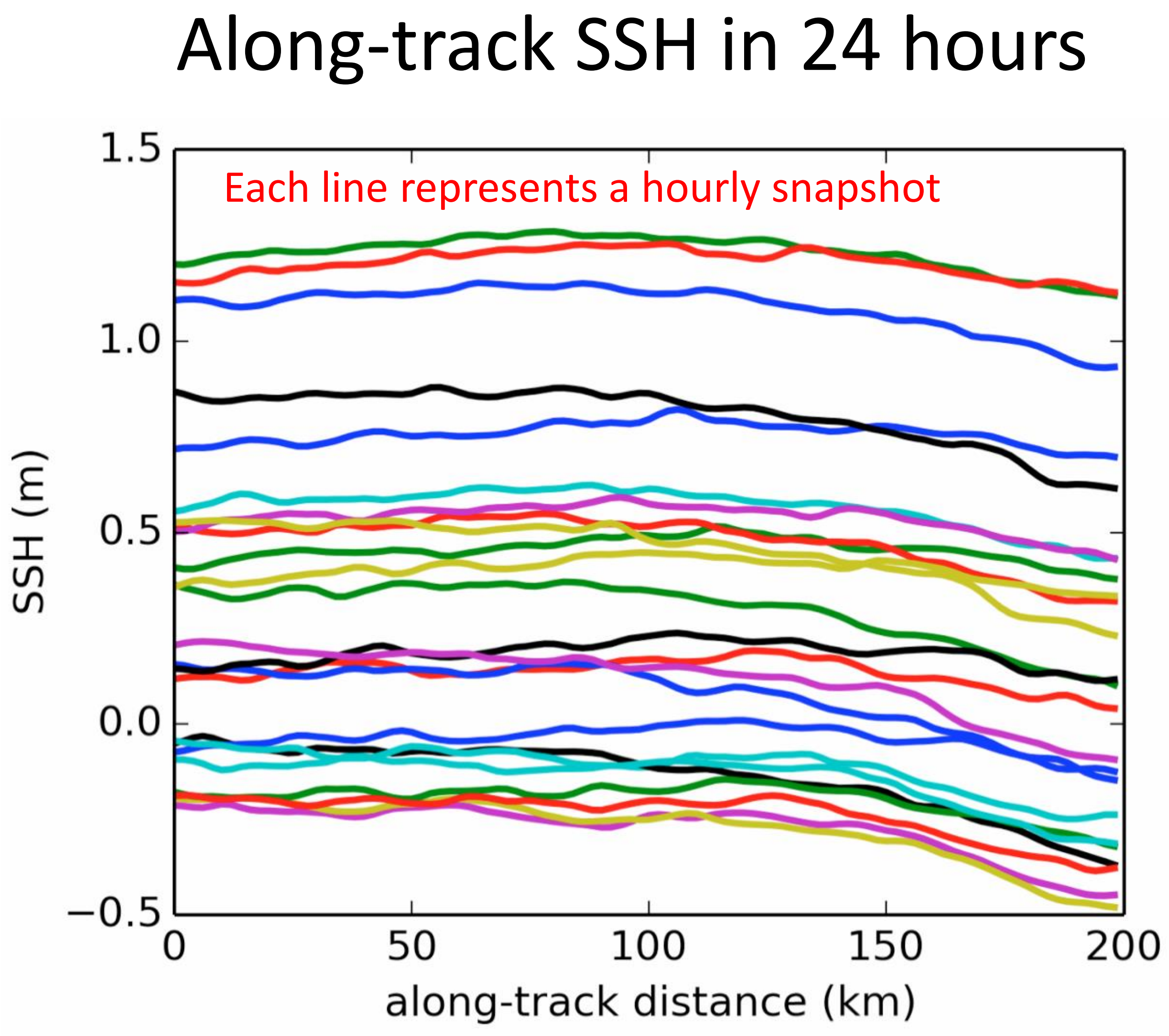


Figure 6. SSH error spectrum requirement (red curve) as a function of wavenumber, given by $E_{SSH}(f) = 2 + 1.25e - 3f^{-2}$. Also shown is the global mean SSH spectrum estimated from the Jason-1 and Jason-2 observations (thick black line), the lower boundary of 68% and 95% of the spectral values (upper gray dotted line and lower gray dotted lines, respectively). The intersections of the two dotted lines with the error spectrum at ~ 15 km (68%) and 30 km (95%) determine the resolving capabilities of the SWOT measurement. The threshold requirement is also shown (blue), which follows the expression $E_{SSH}^{threshold}(f) = 4 + 1.5e - 3\, f^{-2}$.

Rapid changes in SSH at the SWOT scales

Based on model





Reconstruct SSH using in-situ measurements (use hydrostatic approximation)

1. Barotropic component measured by bottom pressure
2. Steric component measured by density profile
3. Inverted-Barometer effect by atmospheric pressure

$$\eta = \frac{p'_b}{\rho_o g} - \frac{p_a}{\rho_o g} - \int_{-H}^{0} \frac{\rho'}{\rho_o} dz,$$

Bottom pressure
Barotropic component

Atmosphere loading

Steric height
Baroclinic component

Instrument performance valuation

To resolve 15-150km wavelengths:

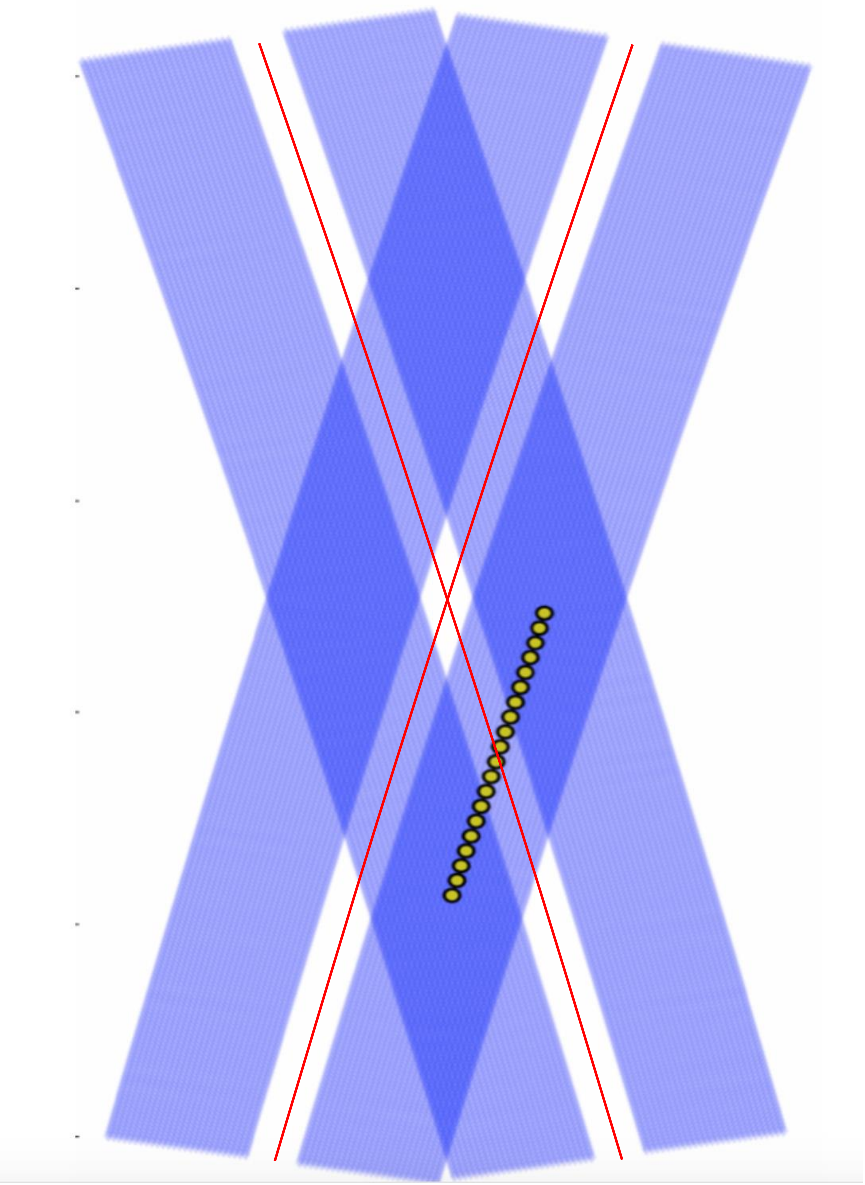
20 locations, 7.5km apart (baseline)

η_i i=1, 20 True SSH without measurement errors

ξ_i Steric height

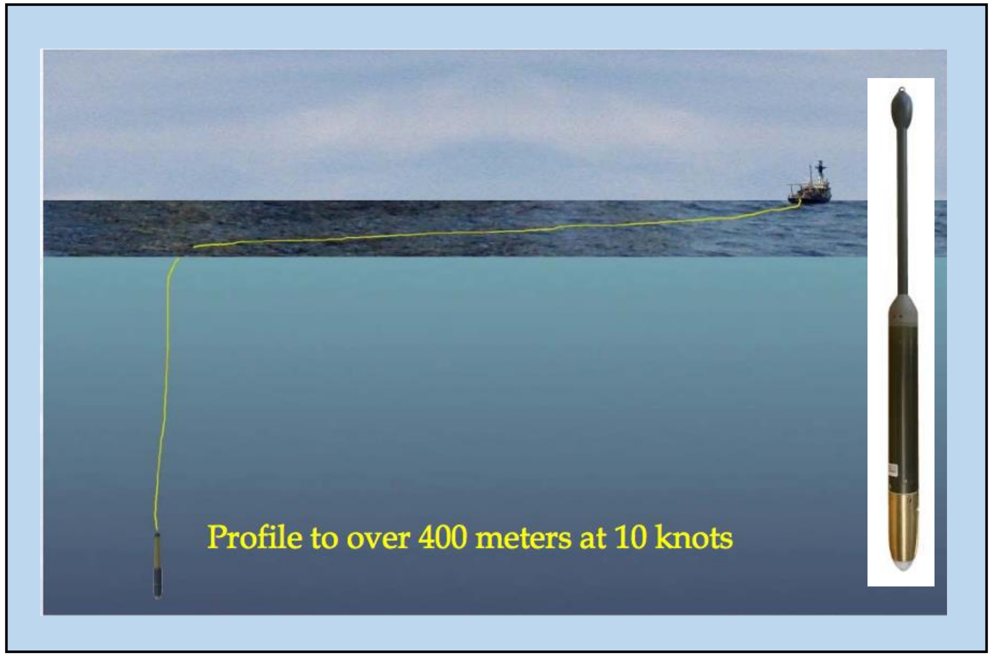
$\eta_i - \xi_i$ Reconstruction error:

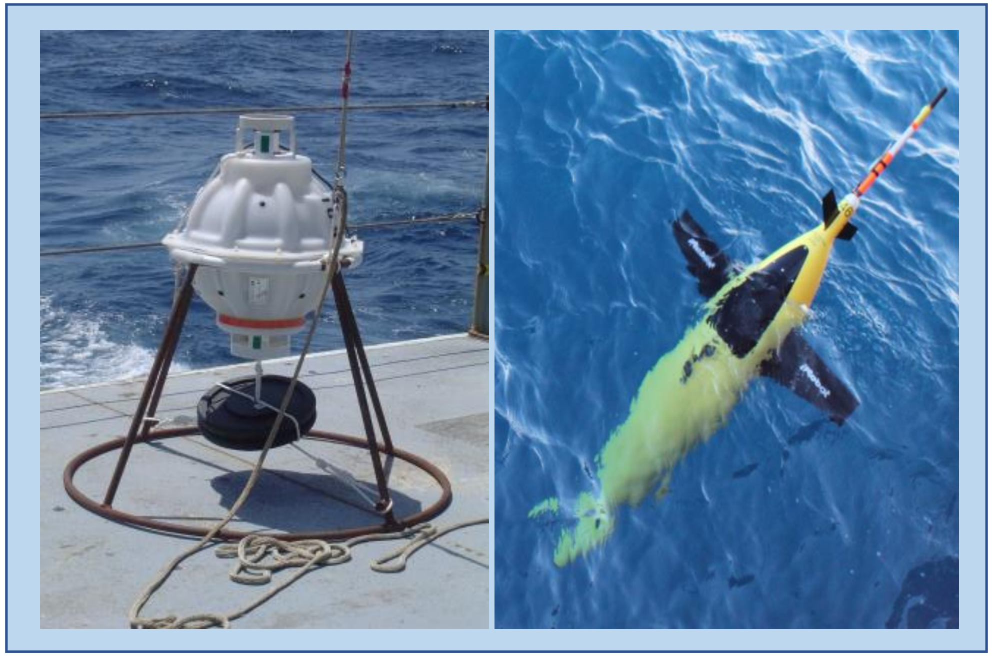
Compare the spectrum of $\eta_i - \xi_i$ to the baseline requirement

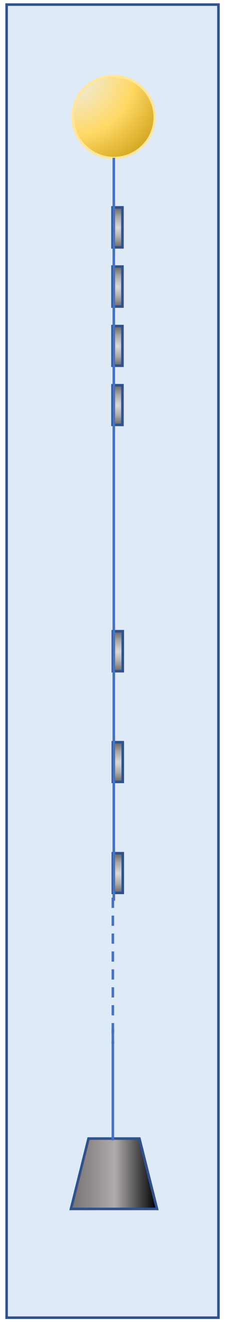


Four instruments

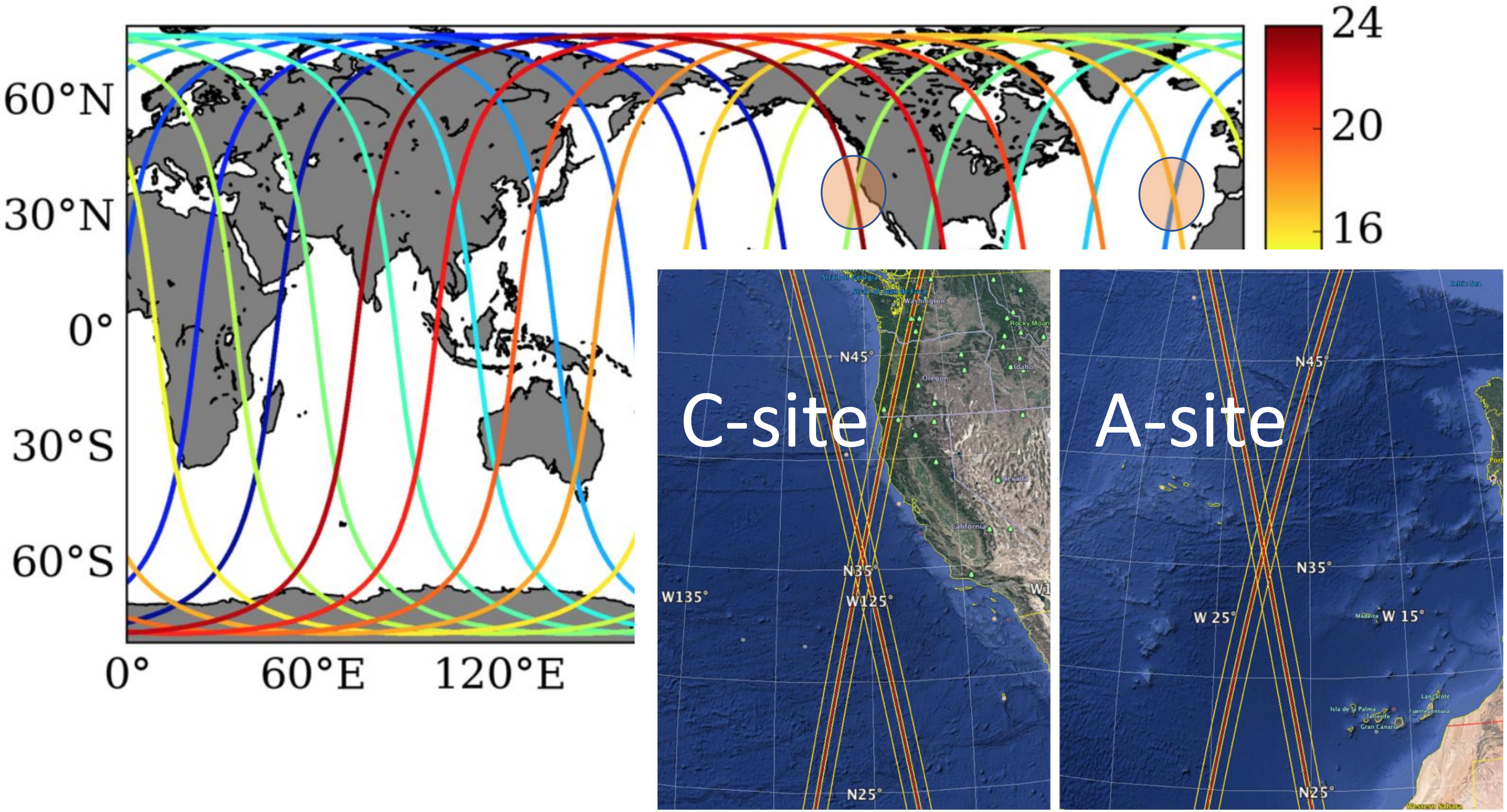
- UCTD (Under-way CTD)
  - Fast upper ocean T/S sampling
  - Compact and portable
  - Needs ship time
  - Finite boat speed
- PIES (Pressure, Inverted Echo Sounder)
  - High frequency sampling
  - Low cost
  - Long duration, easier for logistics
  - Not enough accuracy
- Mooring
  - High frequency sampling
  - Long duration
  - Single point measurement
  - High cost, needs ship time of large-RVs
- Glider
  - Low cost, easy logistics
  - Real-time data transfer
  - Semi-Lagrangian





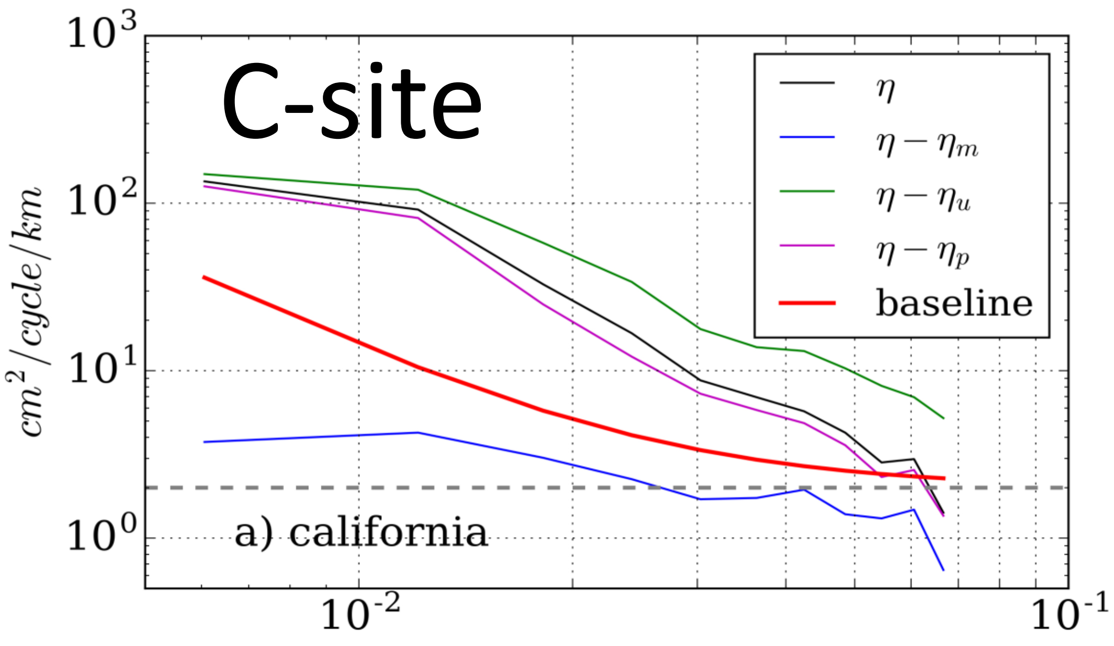


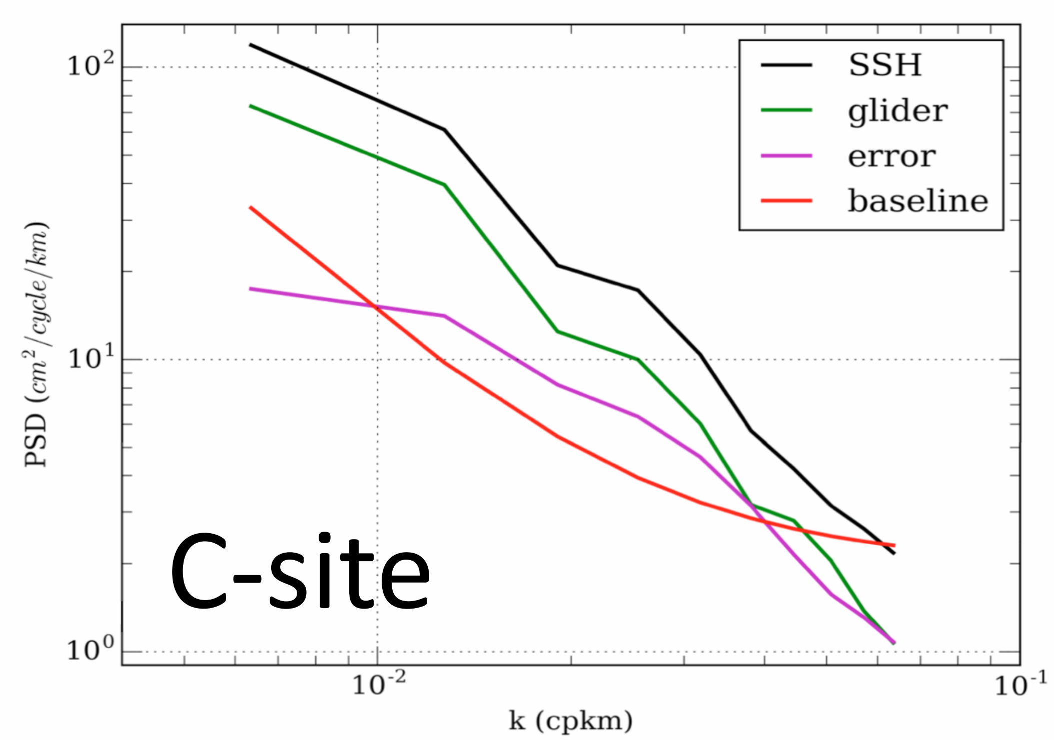
CalVal [Cycle: 1 day; duration: 90 days]

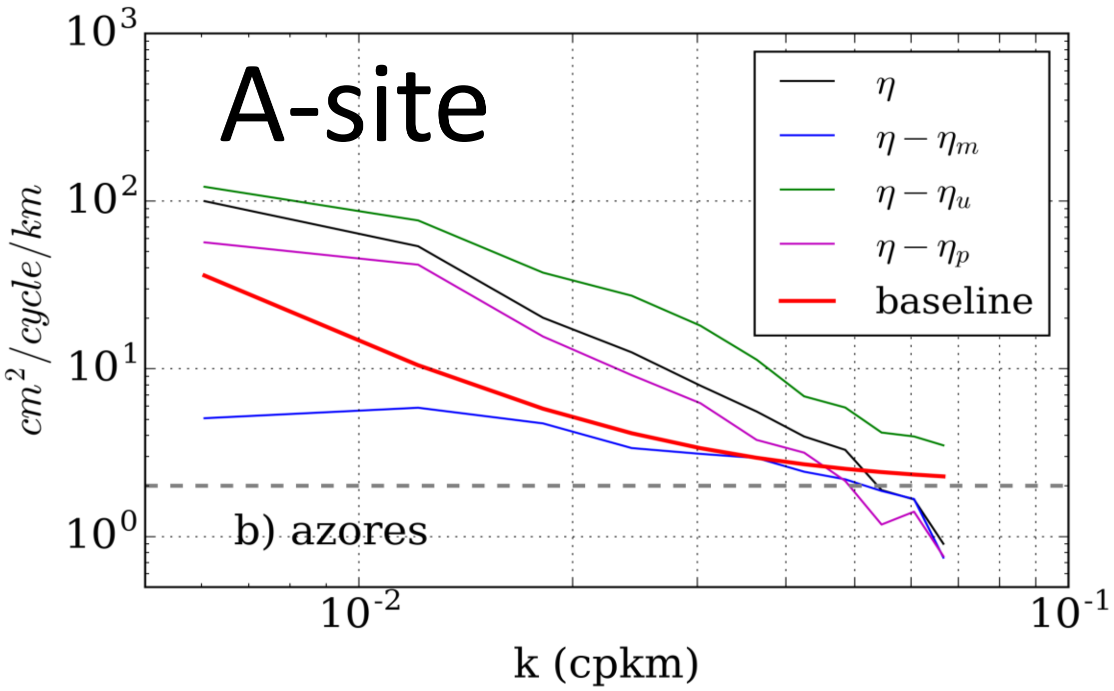


PIES, UCTD, Mooring, Glider

- PIES does not have enough accuracy (~5cm uncertainties)
- Single-boat-UCTD is too slow to capture the synoptic SSH
- Moorings with enough CTDs are robust
- Glider is marginal and needs further test.

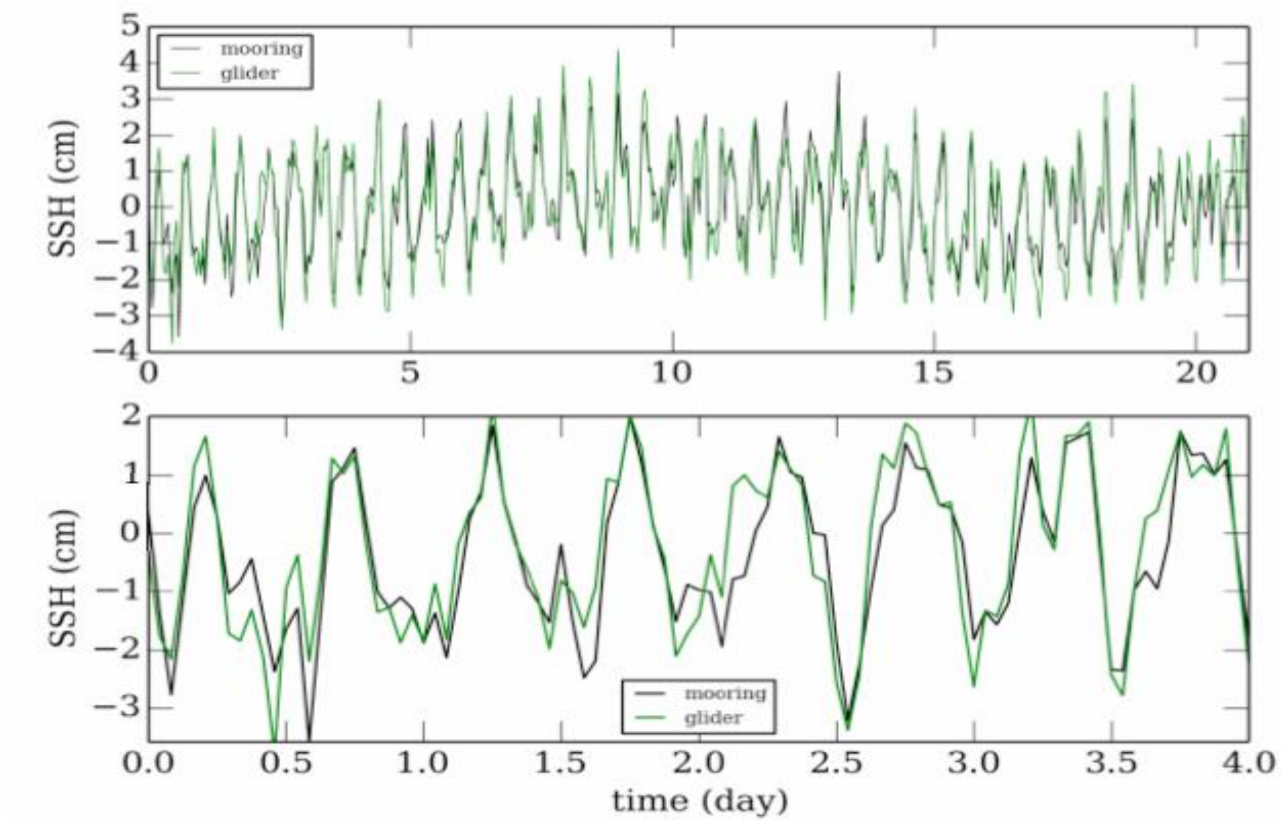




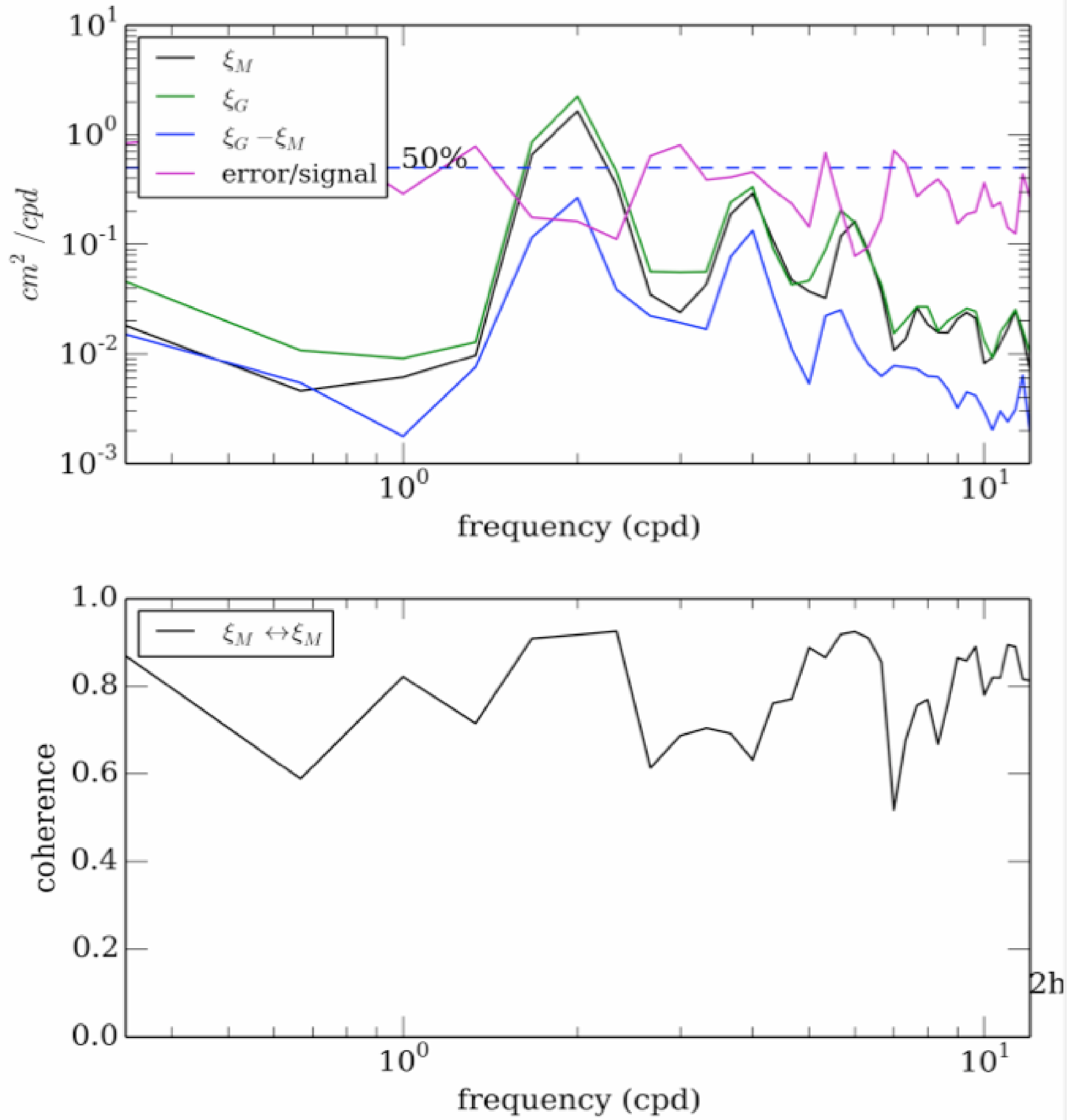


Test glider's performance in Monterey Bay

Preliminary results based on the OSSE near the C-site.



Time series of the upper 500m dynamic height from a mooring (black) and a station-keeping glider (green).



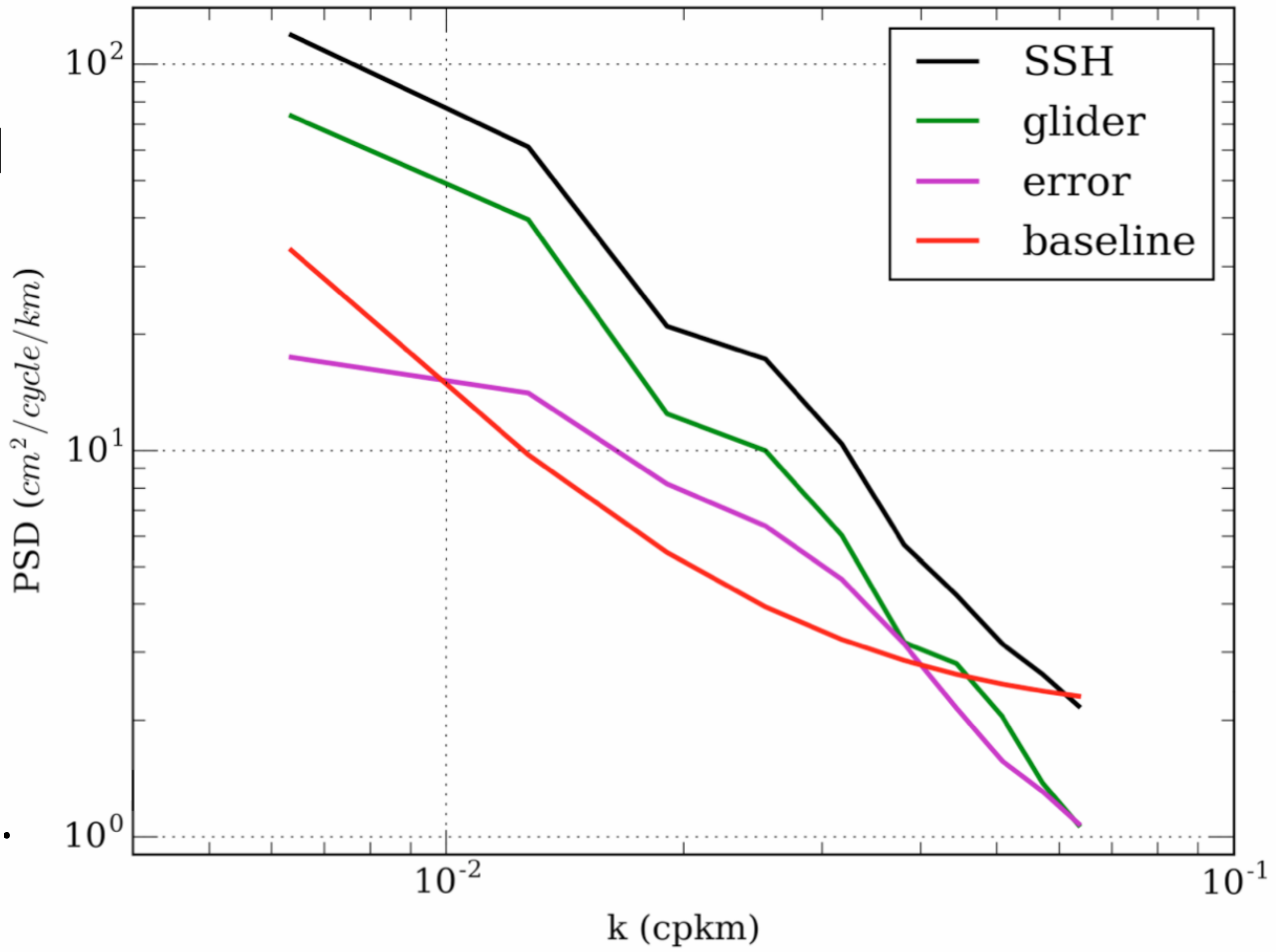
In the frequency space, mooring-glider discrepancy can be large.

Conclusions

- Moorings provide robust high frequency measurements and can be used as a reference for other in-situ platforms.
- An array of gliders can be used as a baseline, but the robustness of gliders needs further test (Yi’ presentation).
- Need to explore the benefit of additional measurements off the baseline-array (Lee’s presentation).

Backup figures

1. 21 Gliders for 90 days
2. 7.5 km spacing resolving [1/15-1/150] wavenumber range
3. Interpolate glider SSH to satellite temporal and spatial grids (simple radial-based interpolation in both space and time).
4. 90 daily-snapshots
5. Gliders marginally meet the requirement.



PIES (Pressure, inverted echo sounder)

- Emits 12kHz sound pulses.
- Measures the round trip travel time of acoustic pulses to sea surface.
- Measures bottom pressure.

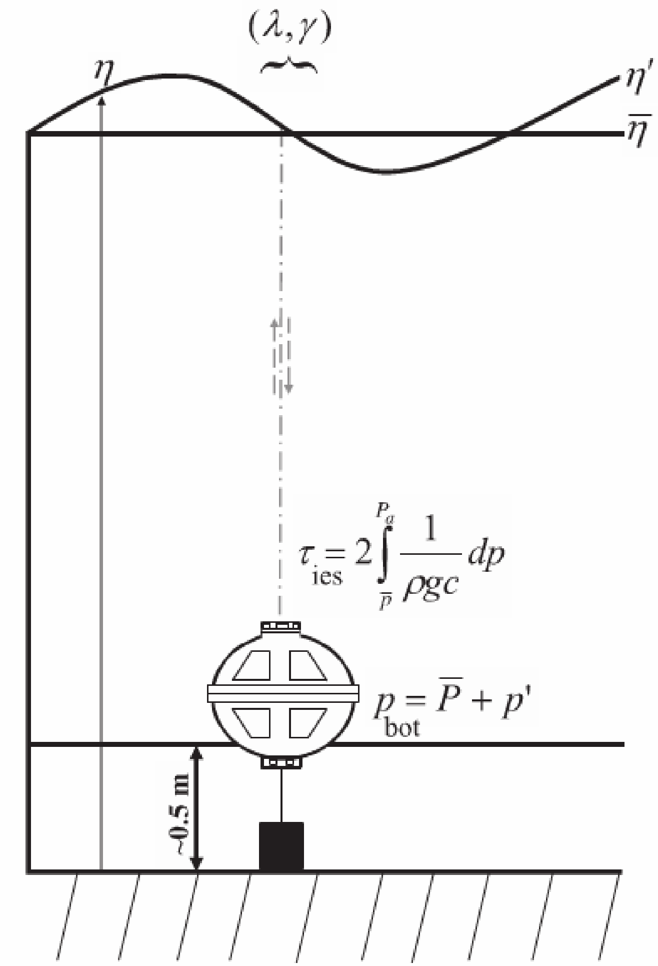
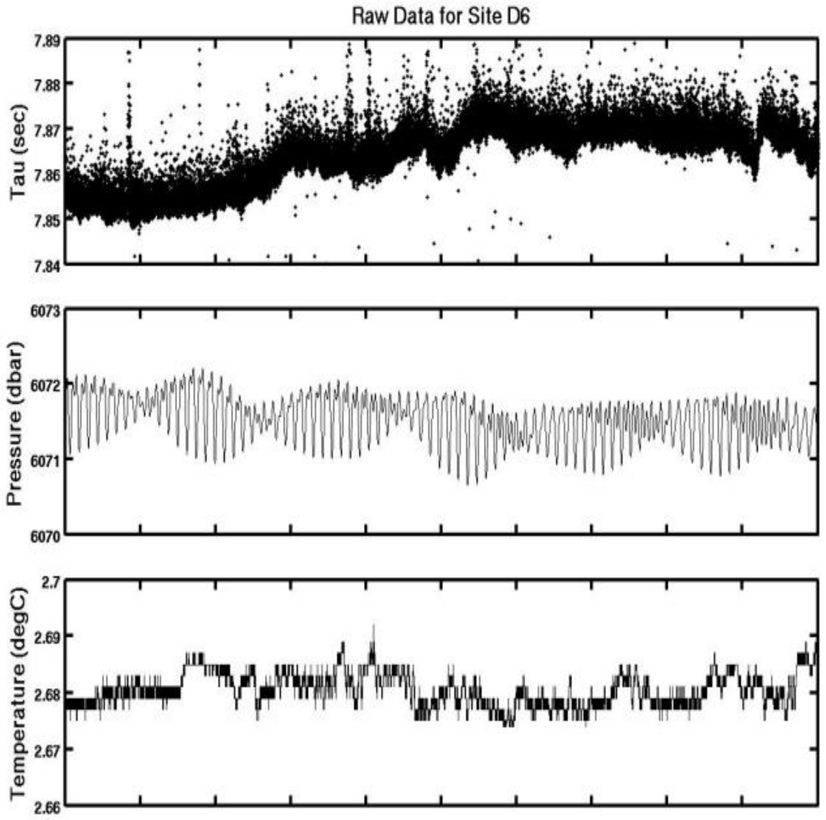


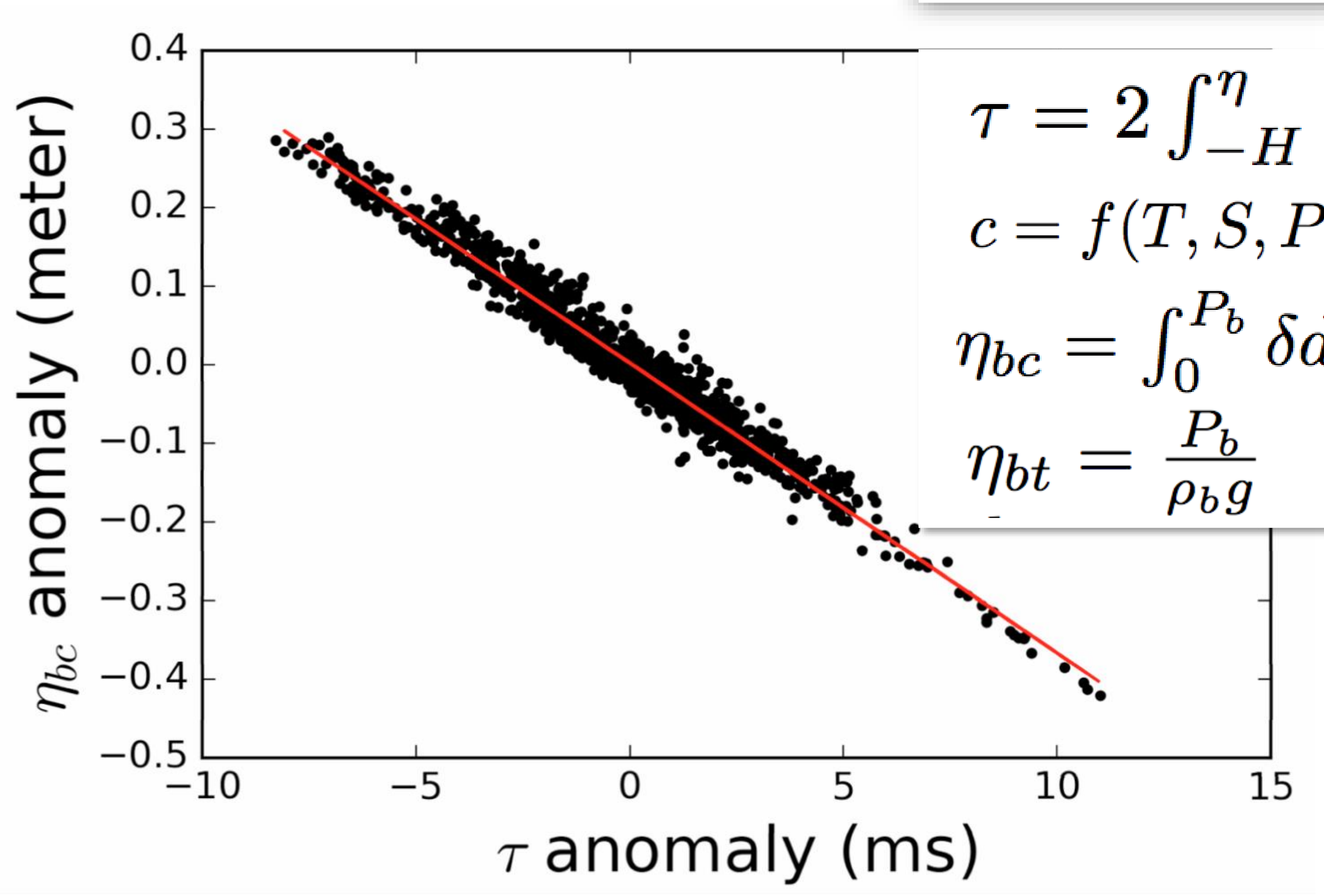
FIG. 2. A PIES instrument moored near the seafloor at latitude λ and longitude γ. Measurements include bottom pressure (p_{bot}) and round-trip acoustic travel time (τ_{ies}).

Baker-Yeboah et al. (2009)



Convert PIES to SSH

$$\eta_P = a_0 + a_1\tau + a_2\tau^2 + \eta_{bt}$$

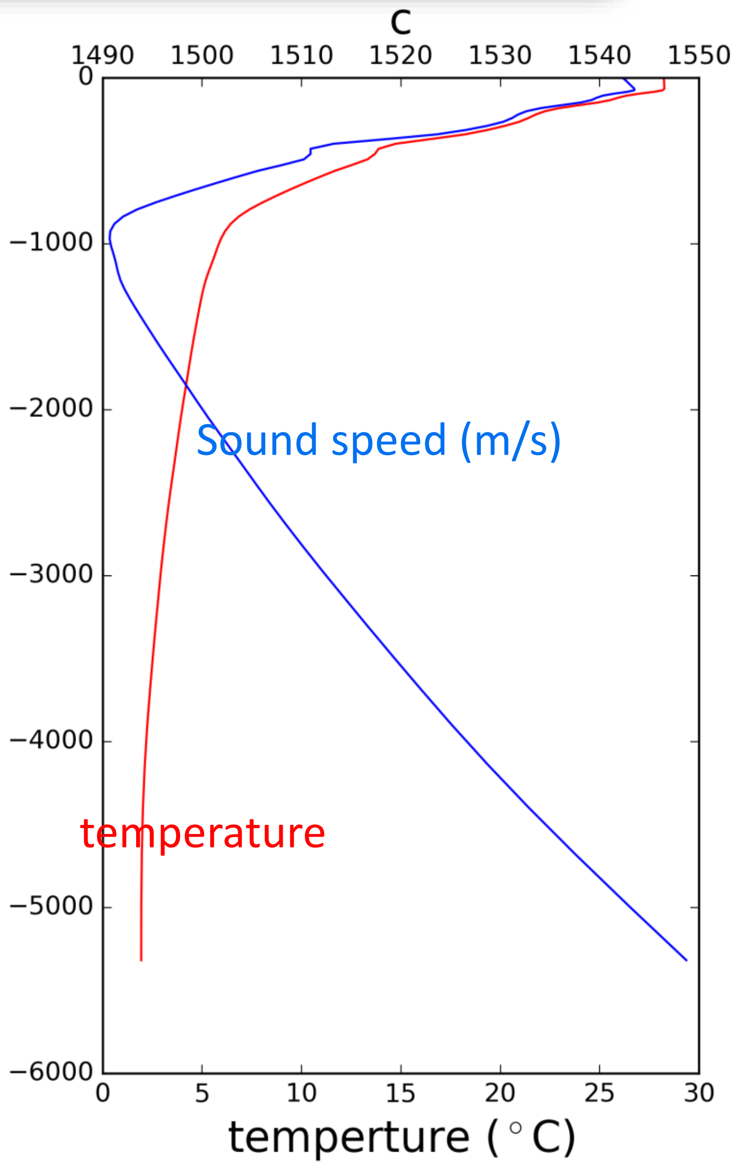


$$\tau = 2\int_{-H}^{\eta} \frac{1}{c}\,dz$$

$$c = f(T, S, P)$$

$$\eta_{bc} = \int_0^{P_b} \delta\, dp$$

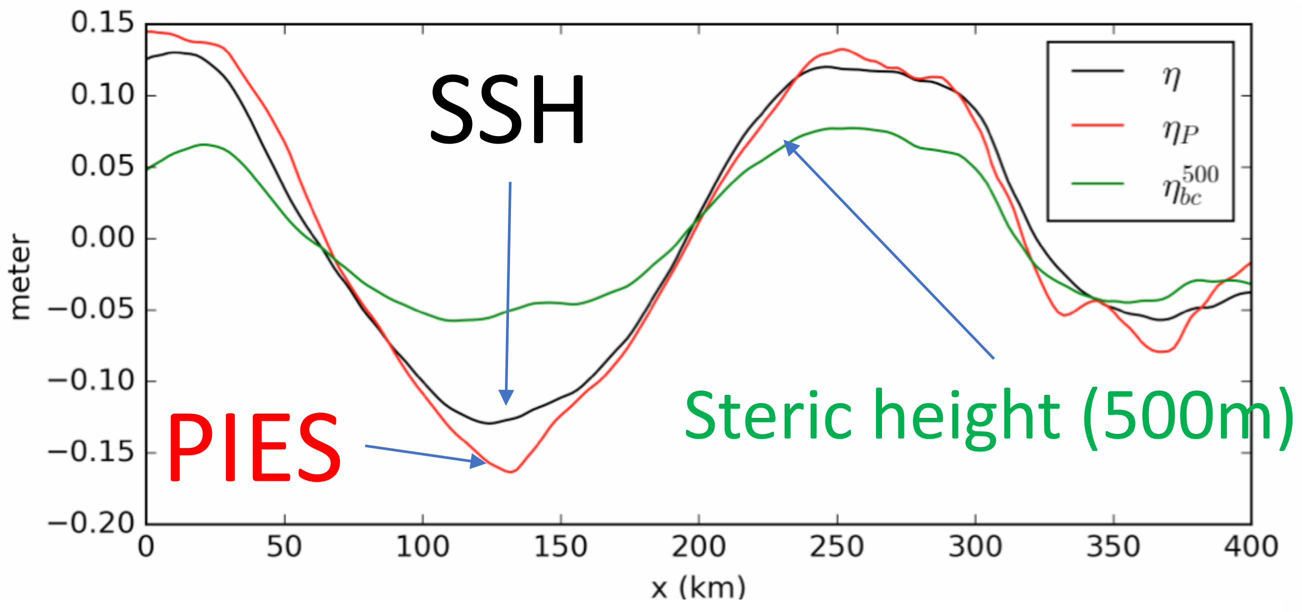
$$\eta_{bt} = \frac{P_b}{\rho_b g}$$

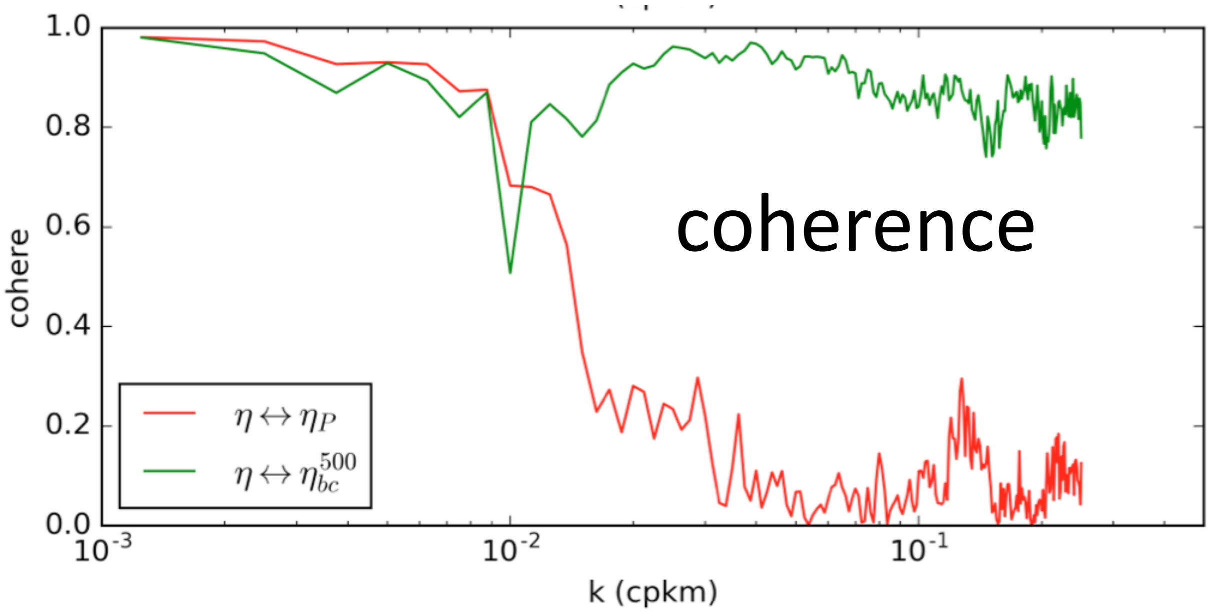


The high correlation between dynamic height and travel time is used to build a lookup curve based on local hydrological data.

The lookup curve is used to convert travel time to dynamic height

PIES does not resolve submeoscale



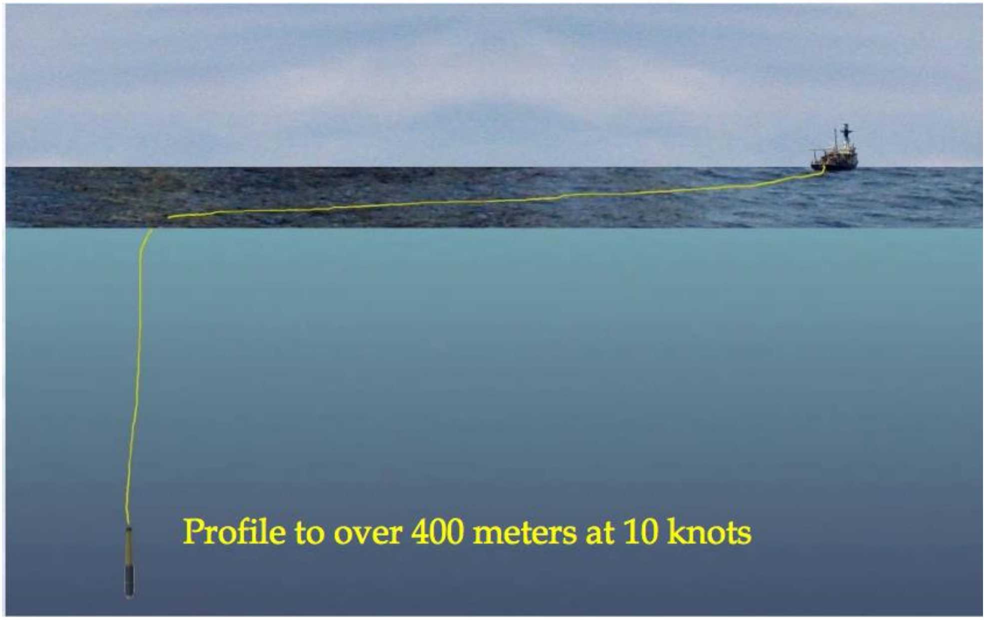


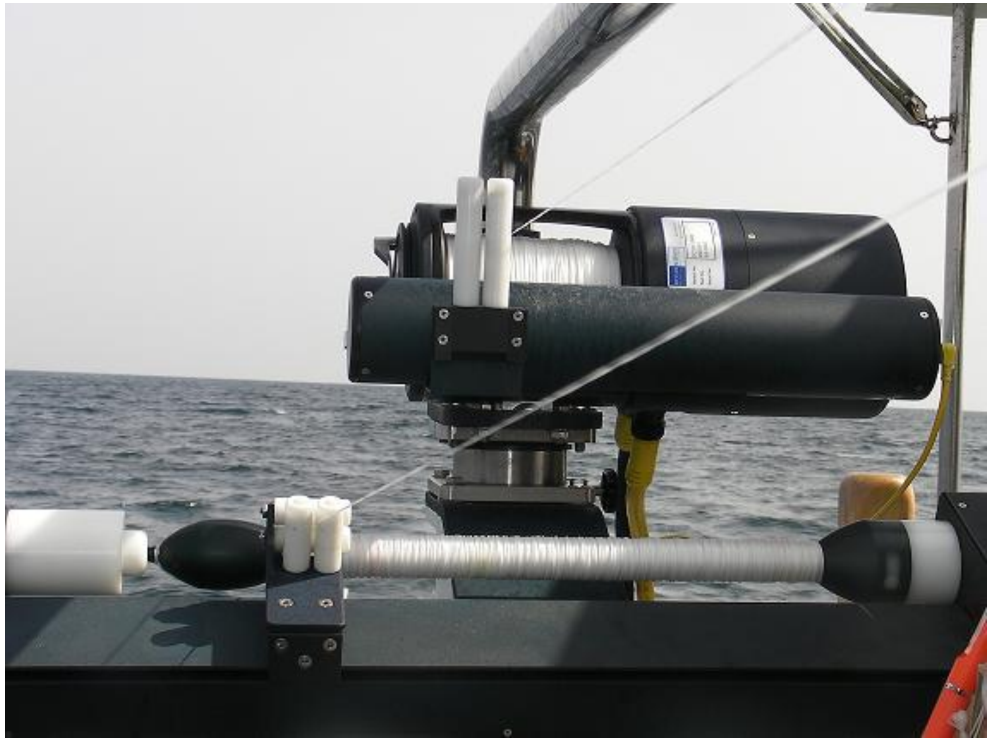
UCTD (Underway CTD)

CTD Profiling from a moving vessel

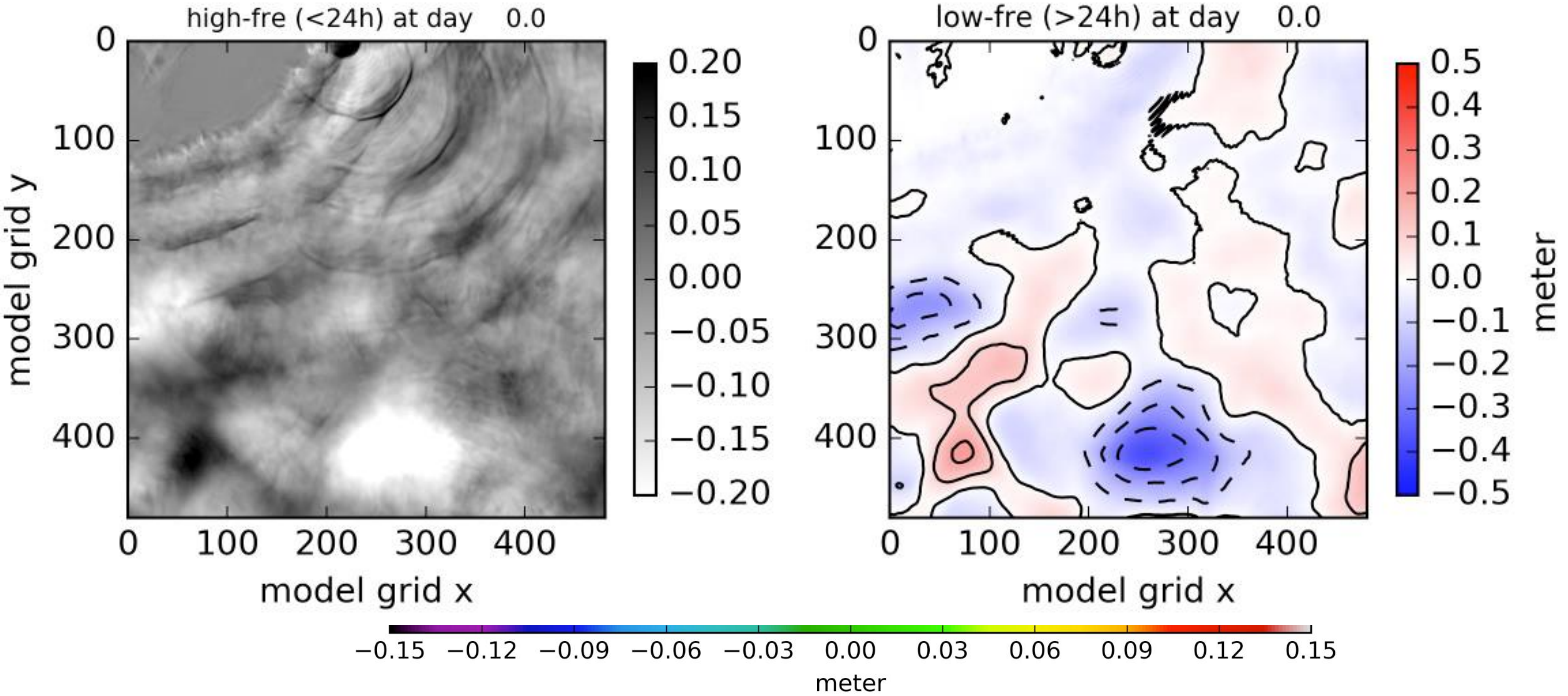
- Achieve over 400-500m vertical profiles while underway at 10kts
- Fast sampling speed (~20min/profile)
- High quality freefall CTD data
- Compact and portable for deployment on multiple vessels

https://youtu.be/P4GO537QVUo

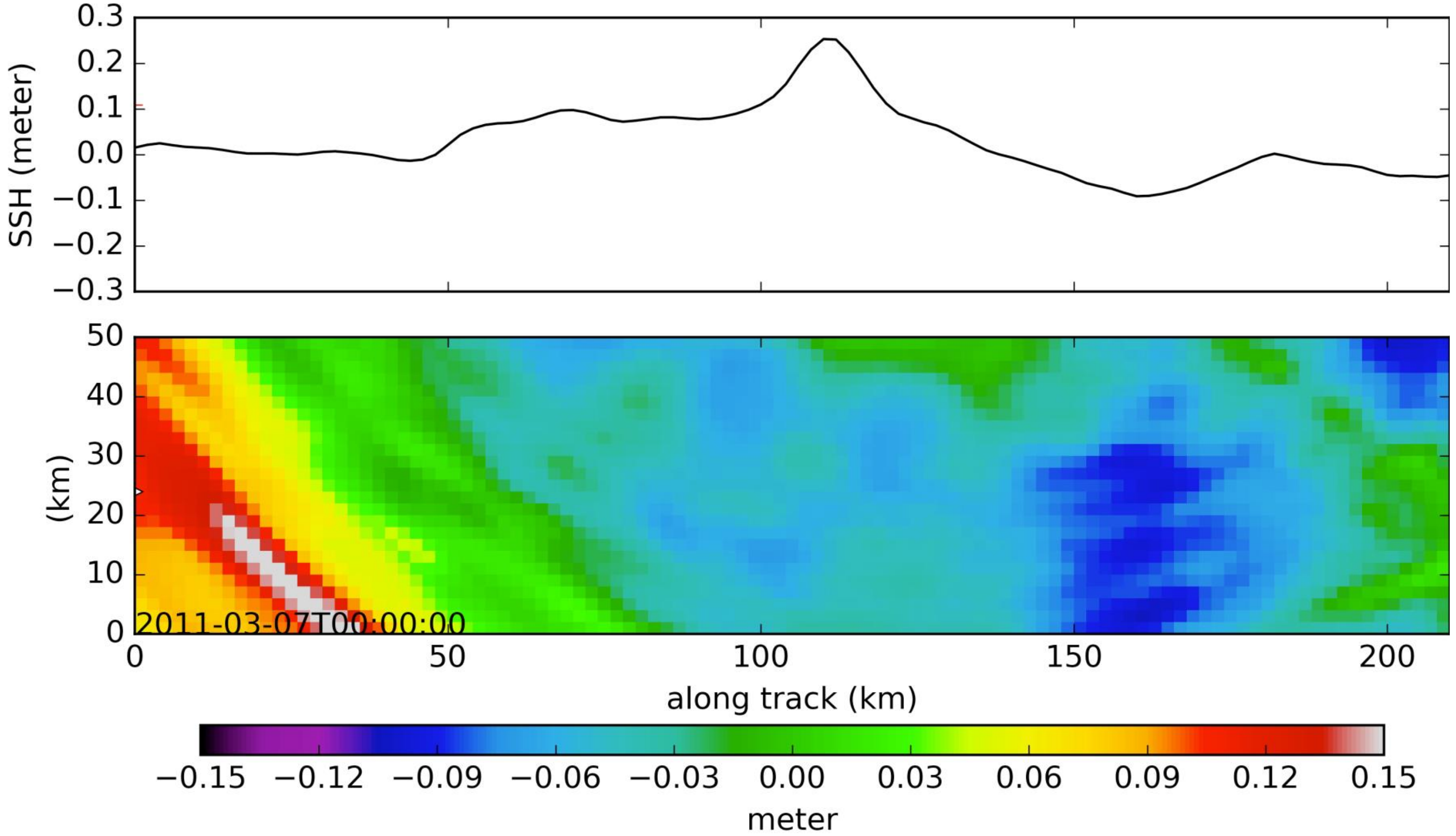




An illustration of the influence of high-frequency motions on the synoptic SSH measurement



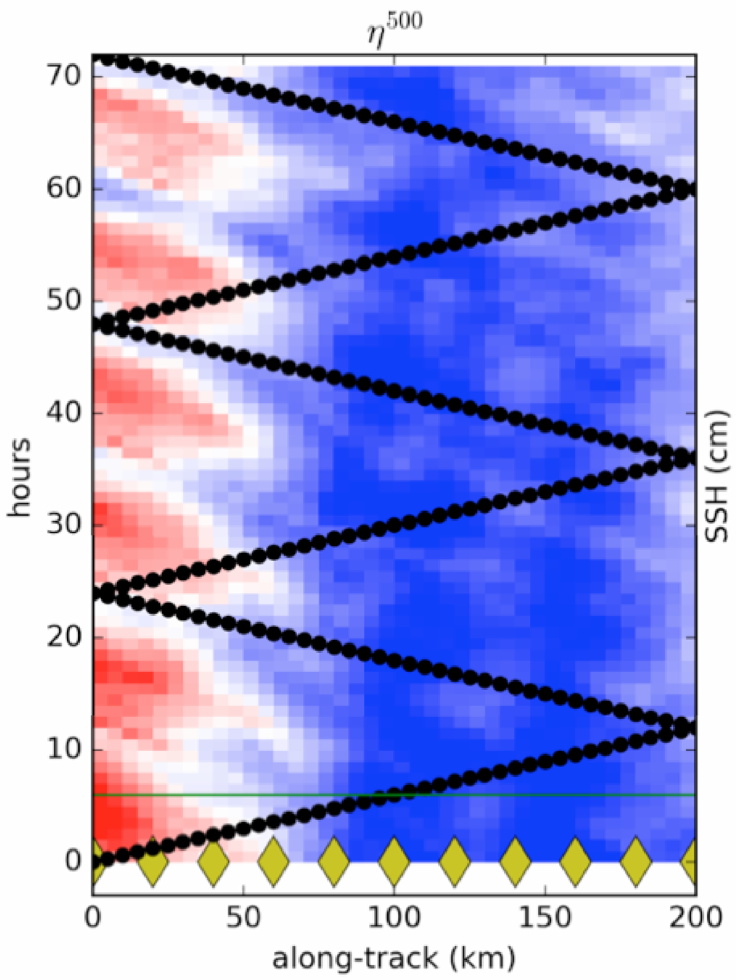
An illustration of the influence of high-frequency motions on the synoptic SSH measurement



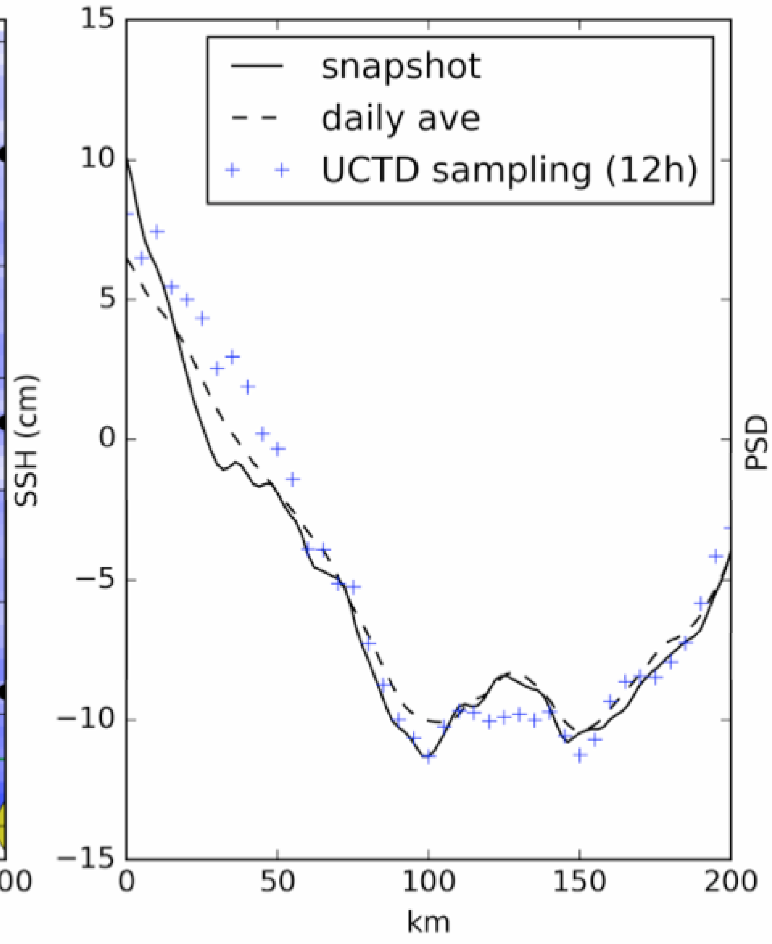
Wikipedia.com

"No man ever steps in the same river twice, for it's not the same river and he's not the same man."

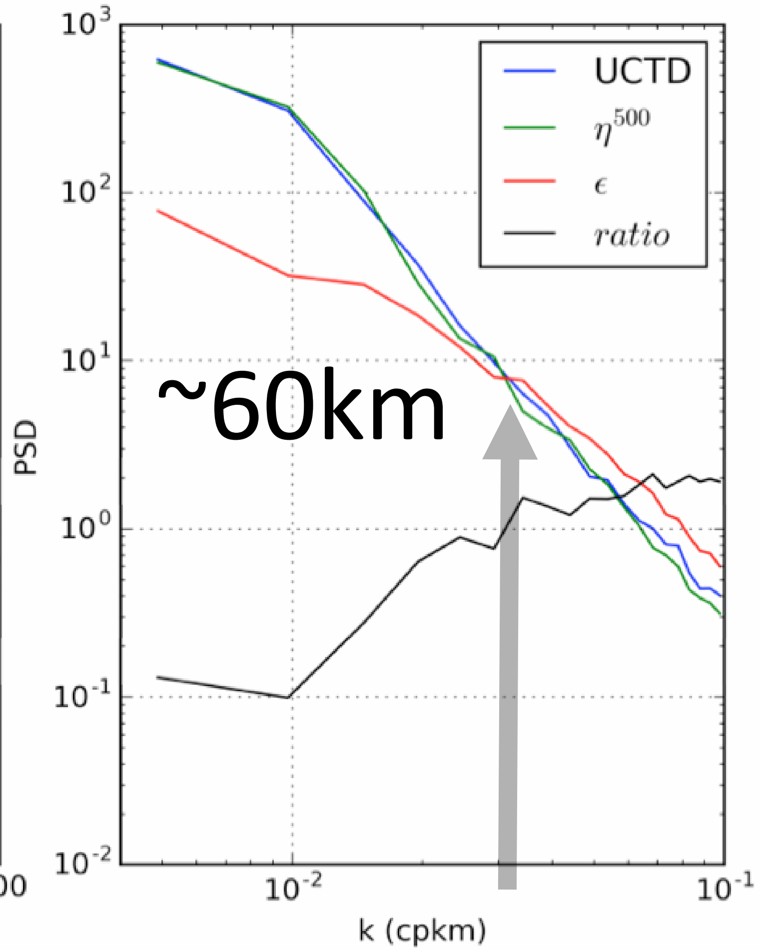
Influence of high frequency motions on UTCD measurements



Color: Hovmöller diagram of the dynamic height based on upper 500m TS.
Dots: UTCD sample tracks in (x,t) coordinate.
Diamonds: PIES along-track location



Along track surface heights



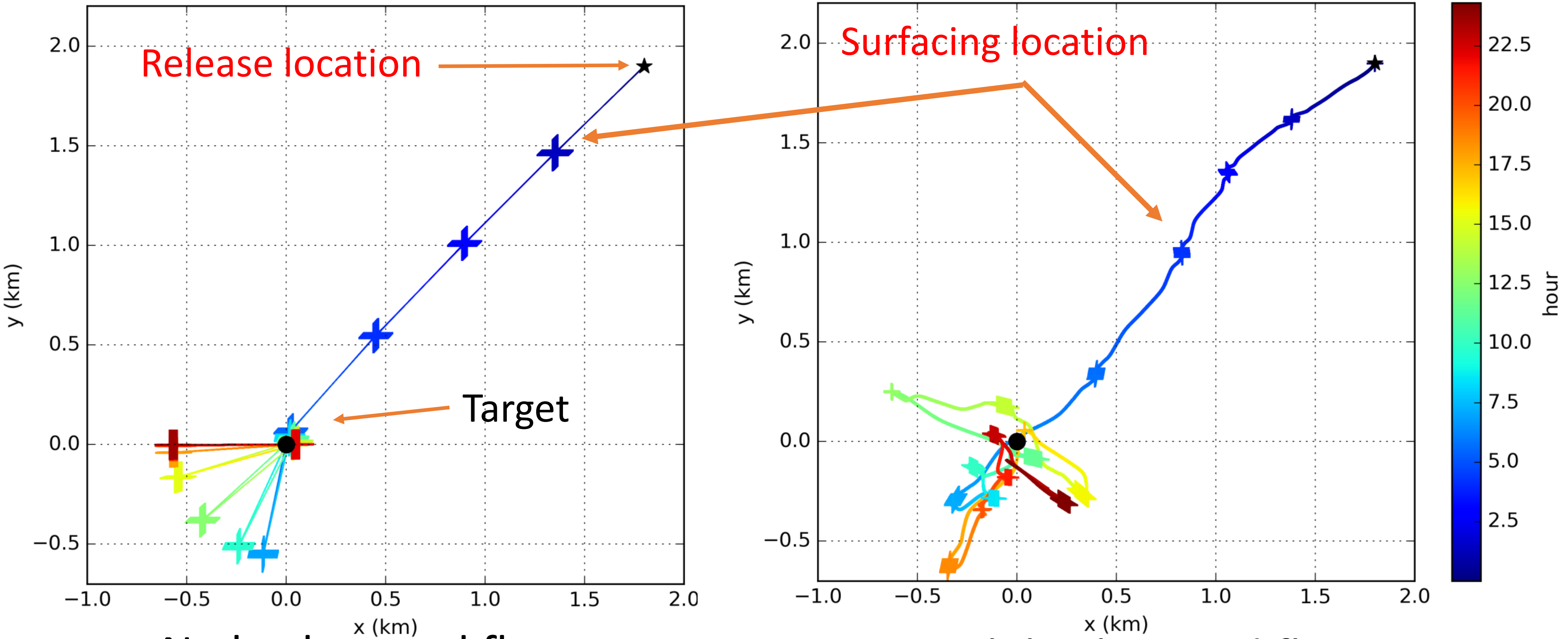
Spectrum and the error-to-signal ratio
Error becomes as large as signal near 60km.

Mooring cost

- \$1.7M for fabrication of moorings
- \$4.6M for instrumentation and deployment/recovery (includes shipping, costs for personnel on cruise)
- \$0.2M (not included above) for shore support, data quality control
- \$3.0M for 75 days ship time (\$2.6M was our last estimate, but the mooring tech says 20 moorings cannot fit on a ship, and so it will add some days to go into port and reload ship)
- ~10M

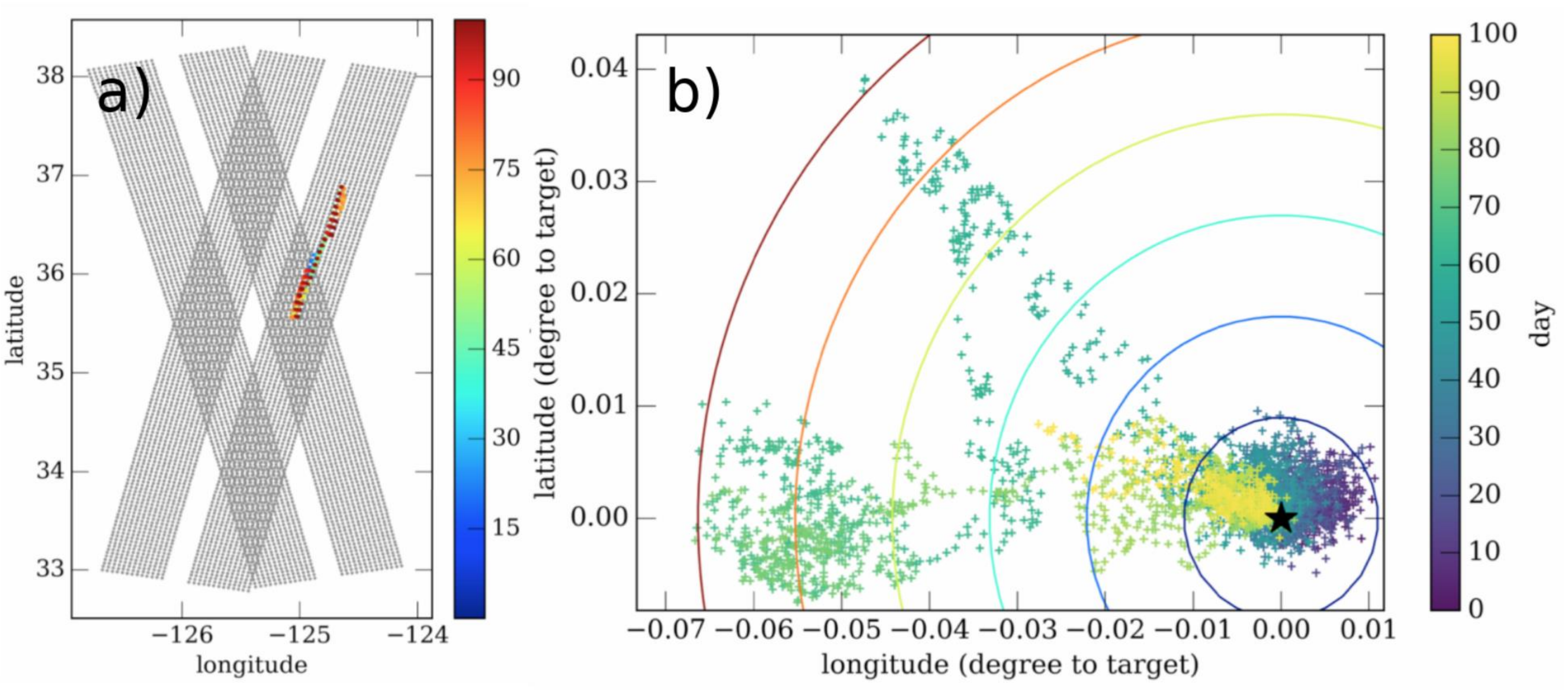
Station-keeping gliders (virtual moorings)

- Fixed GPS target
- One dive per 2 hours for the upper 500m
- Station-keeping within 1 km radius

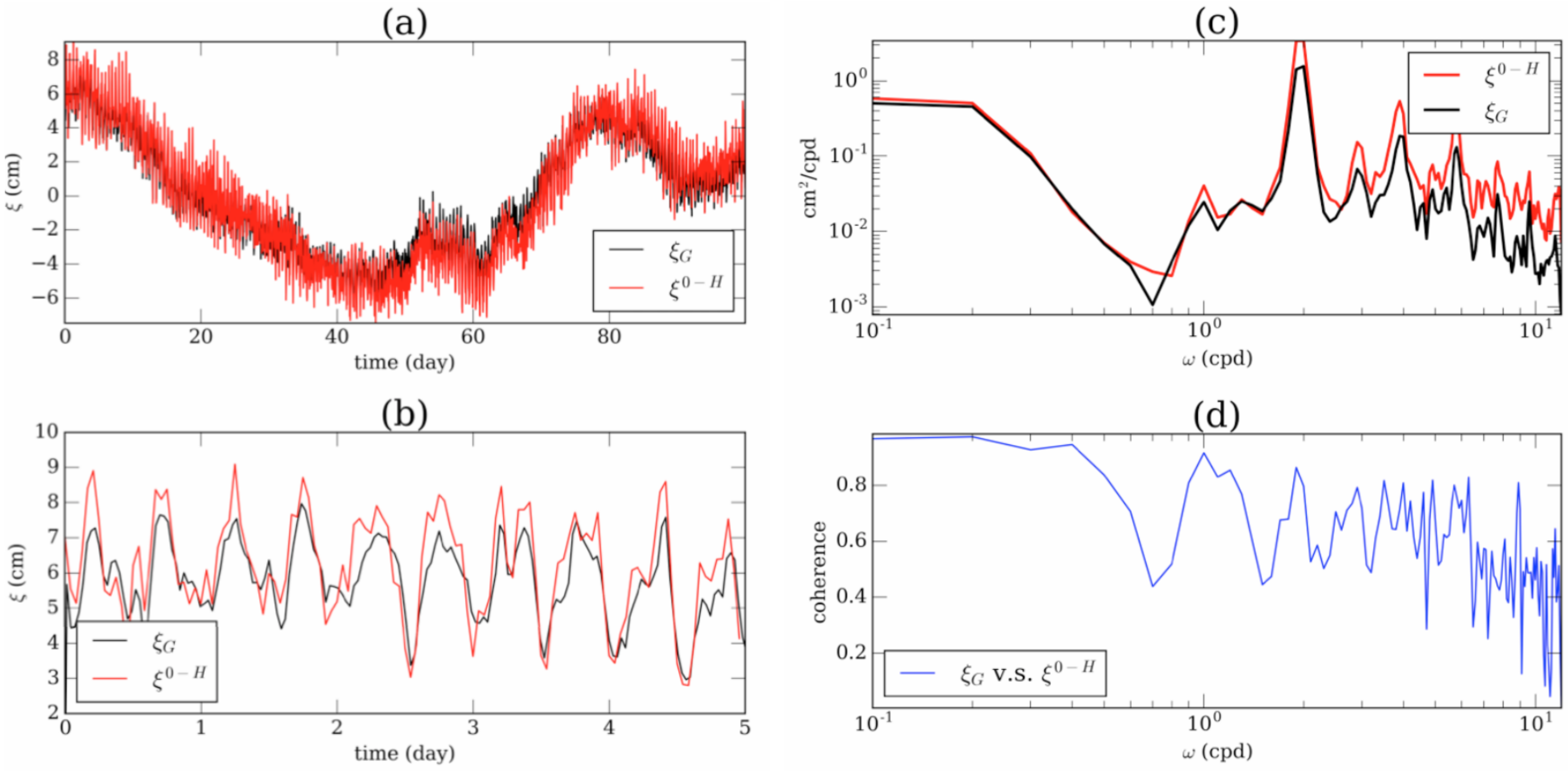


No background flow

With background flow



a)
38
37
36
35
34
33
latitude
−126
−125
−124
longitude
90
75
60
45
30
15
b)
0.04
0.03
0.02
0.01
0.00
latitude (degree to target)
−0.07
−0.06
−0.05
−0.04
−0.03
−0.02
−0.01
0.00
0.01
longitude (degree to target)
100
90
80
70
60
50
40
30
20
10
0
day



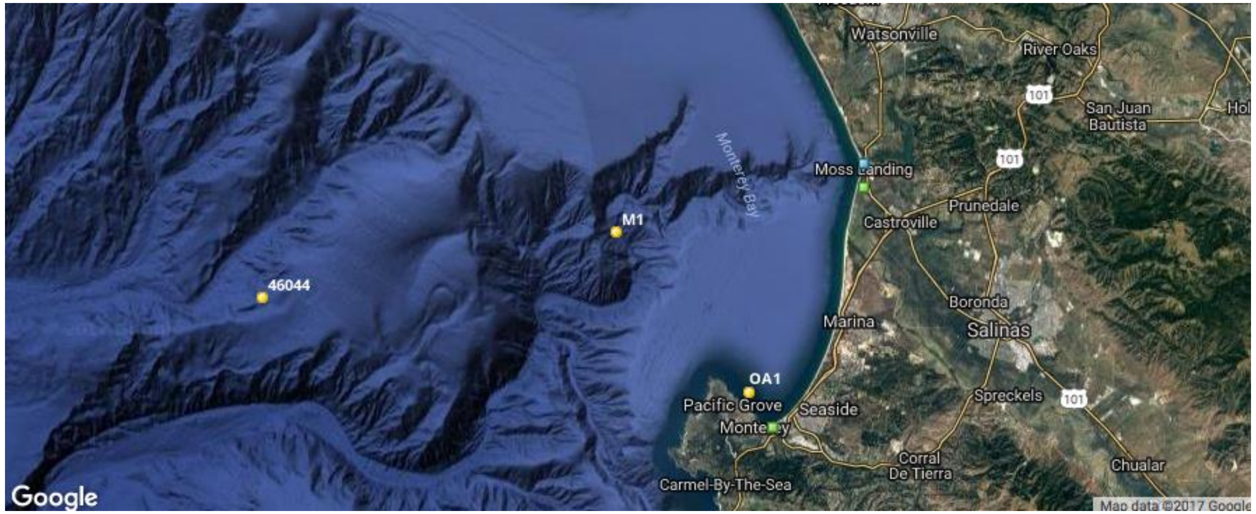
(a)
ξ (cm)
time (day)
ξ_G
ξ^{0-H}
(b)
ξ (cm)
time (day)
ξ_G
ξ^{0-H}
(c)
cm^2/cpd
ω (cpd)
ξ^{0-H}
ξ_G
(d)
coherence
ω (cpd)
ξ_G v.s. ξ^{0-H}

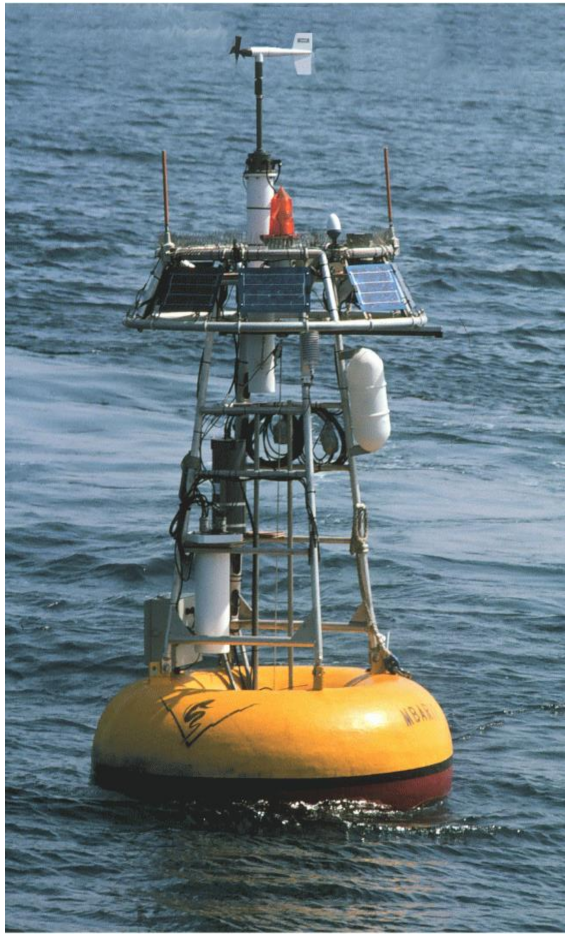
Glider cost

- 90-day operation of one line with 20 station-keeping gliders: $2M
- One 20-glider line: $1.4M
  - One glider for 90-day: $70K
    - ✓ $50K battery/replacement/insurance (30% of the glider cost @ $150K)
    - ✓ $10K shipping & travel
    - ✓ $10K labor for 90-day (1 pilot for 3 gliders)
- Additional cost required: $0.6M
  - Ship (small/medium) time for deployment/recovery ($200K)
  - Project/glider coordination and data management ($200K)
  - Glider control/coordination ($200K)
- Major Advantages
  - Flexible ship schedule in case of launch delay
  - Real-time data access (within hours)
  - Engagement with the glider community (US, France, UK, +)

MBARI M1 Mooring for a pilot experiment

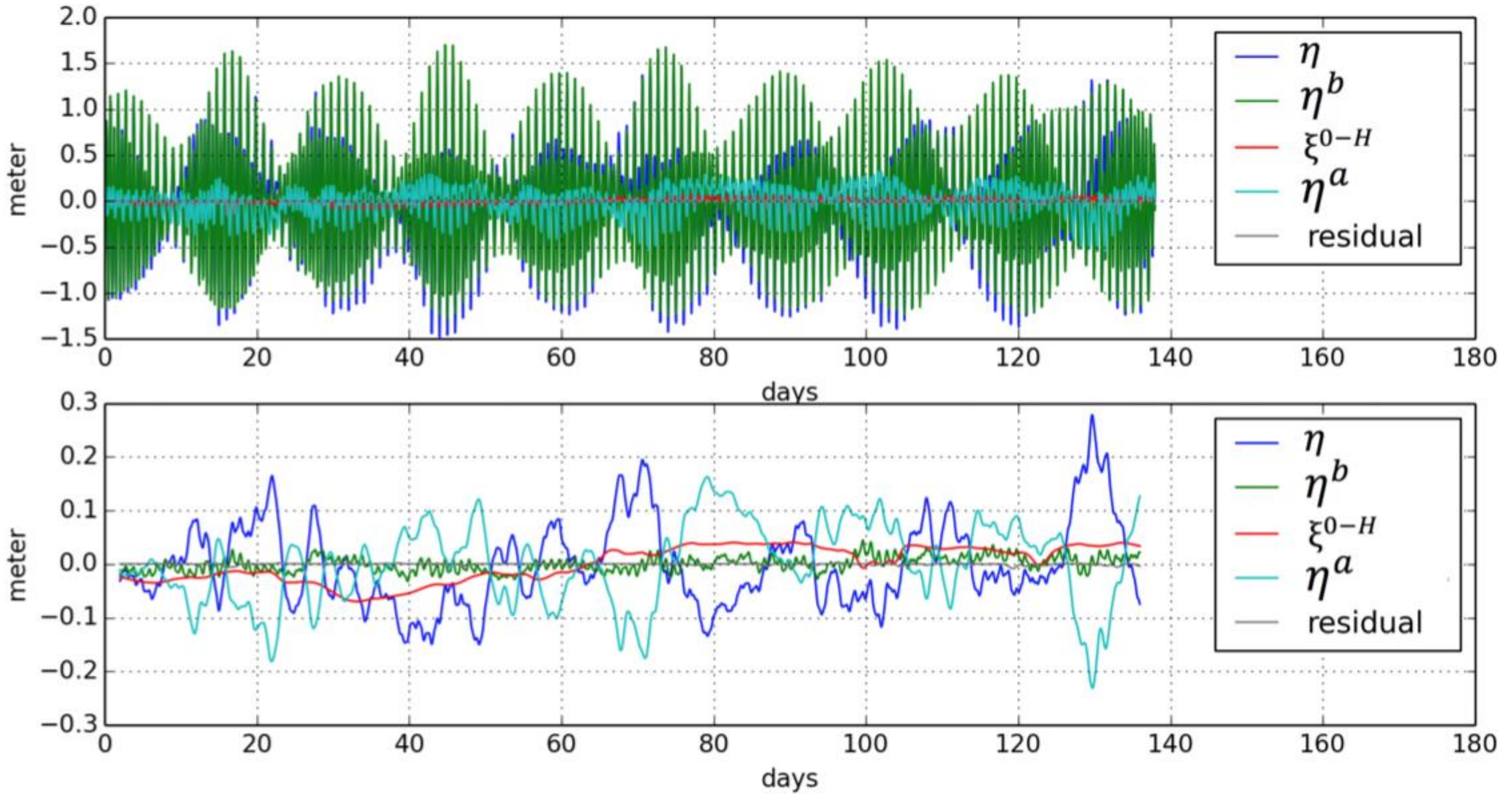
The M1 mooring was deployed in 1989 and is maintained by MBARI. The buoy is equipped with surface and subsurface ocean sensors as well as surface meteorology sensors. The buoy is located at 36.75 N, -122.03 W at a depth of 1000m.





11 CTDs
1m, 10m, 20m, 30m, 40m, 60m, 80m, 100m, 150m, 200m, 300m.
ADCP velocity down to 500 meters.
Other observed variables include Dissolved Oxygen, Fluorescence, pH and CO2.
The surface buoy is equipped with typical meteorological instruments.

Led by Yi Chao, Bruce Haines, Andy Thompson



meter
days
η
η^b
ξ^{0−H}
η^a
residual

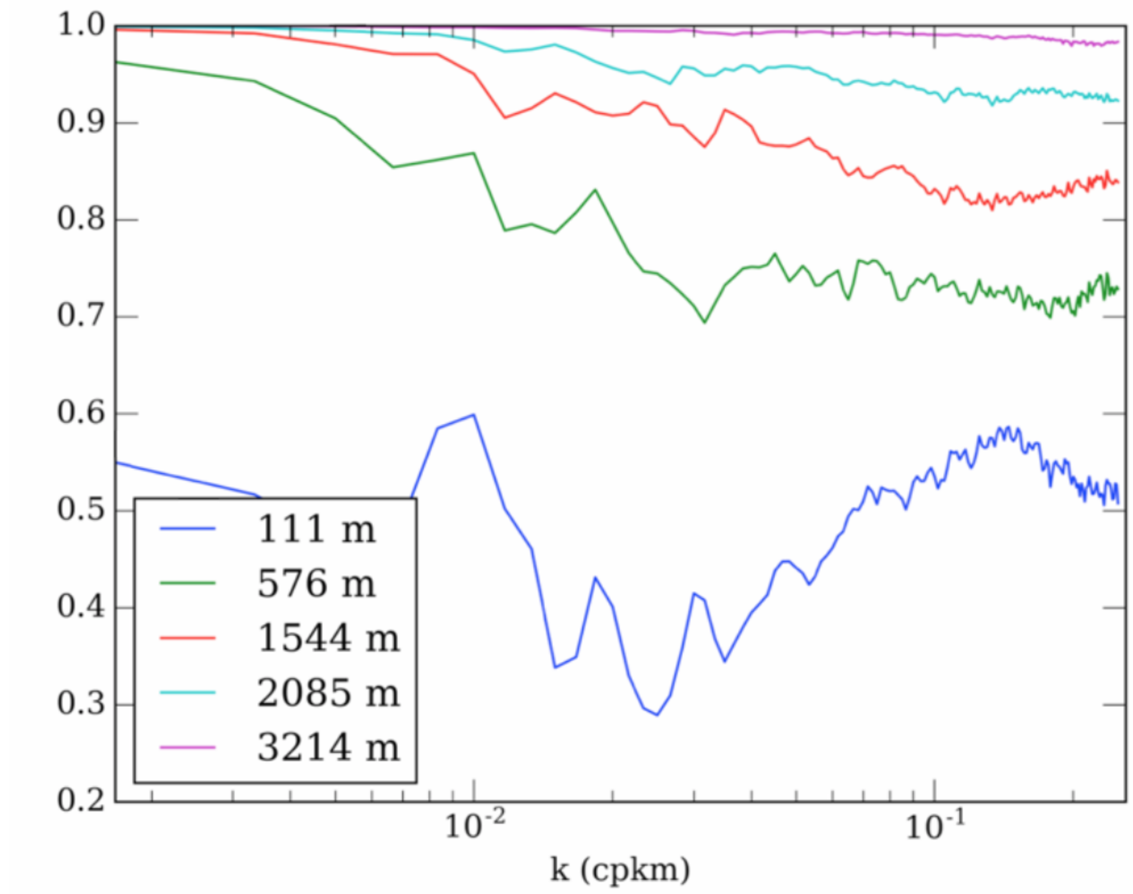


Figure 6. The contribution of the upper ocean steric height to the full-depth steric height defined by the parameter r(z, k) explained in the main text. $r(z_0, k_0)=1$ means that the steric height between the sea surface and z_0 can explain 100% of the full-depth steric height at wavenumber k_0. Each line represents a function r(z, k) at a certain depth denoted in the legend.